

UNITED STATES PATENT APPLICATION

For

**AN INTEGRATED CIRCUIT PACKAGE SUBSTRATE HAVING A THIN
FILM CAPACITOR STRUCTURE**

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AN INTEGRATED CIRCUIT PACKAGE SUBSTRATE HAVING A THIN FILM CAPACITOR STRUCTURE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present patent application is a continuation-in-part of prior U.S. Patent Application No. 10/746,665, filed on December 23, 2003, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1). Field of the Invention

[0001] This invention relates to a capacitor structure that is included in a substrate of an integrated circuit package.

2). Discussion of Related Art

[0002] Integrated circuits are usually manufactured on wafer substrates. Wafer substrate is then “diced” or “singulated” into individual dies, each die carrying a respective integrated circuit. The die is then mounted on a package substrate, often with an intermediate interposer substrate. The substrate or substrates provide structural rigidity to the resulting integrated circuit package. A package substrate also provides x-y transformation from contacts of the die to contacts on a carrier substrate on which the integrated circuit package is mounted.

[0003] Signals can be provided through conductors in the substrate or substrates to and from an integrated circuit in the die. Signal delay, referred to as resistance-capacitance-

inductance delay, often occurs when signals are transmitted through the conductors. In order to reduce resistance-capacitance-inductance delay, a capacitor is often provided close to the die. The capacitor acts as a reservoir of power close to the integrated circuit.

[0004] Discrete capacitors are relatively large and thus take up a large amount of real estate on a substrate. It has been appreciated that thin film capacitors may take up less real estate, which will allow for more capacitors to be formed. It may also be simpler to manufacture thin film capacitors during the manufacture of a substrate than to mount discrete capacitors to a substrate.

[0005] Via openings have to be manufactured in a base structure of a substrate, in which conductive vias have to be formed to which power and ground planes of a thin film capacitor structure have to be connected. The formation of such via openings has been a preoccupation of the semiconductor industry for a number of years. Thus far, all efforts have been directed to drilling openings in low k-value materials such as silicon. Silicon is a brittle material, which makes it difficult to drill openings therein. Each opening also has to be drilled individually, which reduces throughput.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The invention is described by way of examples with reference to the accompanying drawings wherein:

[0007] **Figure 1** is a cross-sectional side view of an interposer substrate manufactured according to an embodiment of the invention;

[0008] **Figure 2** is a cross-sectional side view of an integrated circuit package which includes the interposer substrate of **Figure 1**;

[0009] **Figure 3** is a cross-sectional side view of a package substrate manufactured according to an embodiment of the invention;

[0010] **Figure 4** is a cross-sectional side view of an integrated circuit package that includes the package substrate of **Figure 3**;

[0011] **Figure 5** is a cross-sectional side view of an interposer substrate manufactured according to another embodiment of the invention; and

[0012] **Figure 6** is a cross-sectional side view of an integrated circuit package which includes the interposer substrate of **Figure 5**.

DETAILED DESCRIPTION OF THE INVENTION

[0013] The manufacture of a substrate, such as a package substrate or an interposer substrate, of an integrated circuit package is described. A base structure is formed from a green material having first and second opposing sides and having a plurality of via openings therein. The green material is then sintered so that the green material becomes a sintered ceramic material and the base structure becomes a sintered ceramic base structure having the via openings. A conductive via is formed in each via opening of the sintered ceramic base structure. First and second capacitor structures are formed on the sintered ceramic base structure, each on a respective side of the sintered ceramic base structure. The power and ground planes of the capacitor structure are connected to the vias. As such, a capacitor structure can be formed and connected to the vias without the need to drill via openings in brittle substrates such as silicon substrates. Capacitor structures on opposing sides provide more capacitance without manufacturing complexities associated with the manufacture of one capacitor structure having a large number of power and ground planes.

[0014] **Figure 1** of the accompanying drawings illustrates an interposer substrate 10 which has been constructed according to a method of an embodiment of the invention. The interposer substrate 10 includes a base structure 12, conductive vias 14, a capacitor structure 16 having a high k-value dielectric material, a low k-value dielectric material 18, and contact pads 20.

[0015] The base structure 12 is initially made from a green, i.e., unsintered material. The green material is packaged in the shape of the base structure 12 and via openings 22 are then punched through the green material. Handling, packaging, and punching of green material is known in the art. An advantage of punching holes in a green material is that the green

material is not as brittle as other substrates such as silicon substrates. The green material is subsequently sintered so that the green material becomes a sintered ceramic material and the base structure 12 becomes a sintered ceramic base structure 12. The sintered ceramic base structure 12 then has the via openings 22. The via openings 22 include a power via opening 22P, a ground via opening 22G, and signal via openings 22S. Each one of the via openings 22 extends from a lower surface through an upper surface of the horizontal sintered ceramic base structure 12.

[0016] The low k-value dielectric material 18 is then formed over the entire upper surface of the sintered ceramic base structure 12. The low k-value dielectric material 18 thus covers the power, ground and signal via openings 22P, 22G, and 22S. The low k-value dielectric material 18 is typically made of silicon dioxide, which has a dielectric constant of between three and four.

[0017] The low k-value dielectric material 18 is subsequently patterned. The low k-value dielectric material 18 may, for example, be patterned by first covering a portion thereof and then burning exposed portions away. The portions that are burned away (or etched) are portions thereof located over the power and ground via openings 22P and 22G. Openings are also burned (or etched) in the low k-value dielectric material 18 so that the signal via openings 22S extend vertically through the low k-value dielectric material 18.

[0018] The capacitor structure 16 is then formed on the sintered ceramic base structure 12 where the low k-value dielectric material 18 has been burned away (or etched). That is, the capacitor structure 16 is formed on an area of the upper surface of the sintered ceramic base structure 12 that has the power and ground via openings 22P and 22G. The capacitor structure 16 includes power and ground planes 24 and 26 and a dielectric layer 28. The power and ground planes are typically made of copper or platinum. The dielectric layer 28 is

made of a high k-value dielectric material which may have a dielectric constant of between 300 and 900, although the dielectric constant may be as high as 3000. An insulating layer 30 is formed on top of the ground plane 26 in order to add a second capacitance and is made of the same material as the dielectric layer 28. More layers could be added for extra capacitance. The layers and planes 24, 26, 28, and 30 are all patterned so that the power and ground via openings 22P and 22G extend vertically through the entire capacitor structure 16. The manufacture of thin film capacitor structures such as the capacitor structure 16 is known in the art.

[0019] The via openings 22 are all subsequently filled with the conductive vias 14. The conductive vias 14 are typically formed from a conductive metal such as copper, silver, or an alloy of tungsten and molybdenum. The conductive vias may, for example, be sputter-deposited, plated, or printed within the via openings 22. The conductive vias 14 include power, ground and signal conductive vias 14P, 14G and 14S in the power, ground, and signal via openings 22P, 22G and 22S, respectively. The power conductive via 14P is in contact with the power plane 24 and is not connected to the ground plane 26. The ground conductive via 14G is in contact with the ground plane 26 and is not connected to the power plane 24. Each signal conductive via 14S is electrically disconnected from all other conductive vias 14P, 14G, and 14S.

[0020] The contact pads 20 are then formed on the capacitor structure 16 and the low k-value dielectric material 18. Each contact pad 20 is located on and is electrically connected to a respective one of the conductive vias 14.

[0021] **Figure 2** illustrates the interposer substrate 10 within an integrated circuit package 34 according to an embodiment of the invention. The integrated circuit package 34 further includes a carrier substrate 36, a package substrate 38, a die 40, and respective sets of

conductive interconnection members 42, 44, and 46.

[0022] The package substrate 38 has a base structure 48, a plurality of conductive lines 50 within the base structure 48, a plurality of contact pads 52 on a lower surface of the base structure 48, and a plurality of contact pads 54 on an upper surface of the base structure 48. The base structure 48 is made of a low k-value dielectric material. In the given example, each one of the conductive lines 50 interconnects a respective one of the contact pads 52 with a respective one of the contact pads 54. Some of the conductive lines 50 have two vertical vias 56 and 58 that are interconnected by a horizontal line 60. The inclusion of the horizontal line 60 allows for the contact pads 54 to be offset with respect to the contact pads 52. The conductive lines 50 thus allow for an x-y transformation from the contact pads 52 to the contact pads 54.

[0023] As illustrated, the interposer substrate 10 further has a plurality of contact pads 62 on a lower surface of a sintered ceramic base structure 12. There is no x-y transformation from the contact pads 62 at the lower side of the interposer substrate 10 to the contact pads 20 at the upper side of the interposer substrate 10. Each one of the contact pads 62 matches up with a respective one of the contact pads 54, and a respective one of the conductive interconnection members 44 interconnects a respective one of the contact pads 62 with a respective one of the contact pads 54.

[0024] The die 40 has an integrated circuit formed in a lower surface thereof. A plurality of contact pads 64 are formed on a lower surface of the die 40 and are electrically connected to the integrated circuit. Each one of the contact pads 64 matches up with a respective one of the contact pads 20 and is connected thereto by a respective one of the conductive interconnection members 46. It can thus be seen that there is no x-y transformation from the contact pads 64 to the contact pads 54, and that there is an x-y transformation from the

contact pads 54 to the contact pads 52.

[0025] The carrier substrate 36 has a respective base structure 66 and a plurality of contact pads 68 formed on an upper surface of the base structure 66. Each one of the contact pads 52 is aligned with a respective one of the contact pads 68 and is connected thereto by a respective one of the conductive interconnection members 42.

[0026] **Figure 3** illustrates a package substrate 138 which is manufactured according to a method of another embodiment of the invention. The package substrate 138 includes a sintered ceramic base structure 112, a capacitor structure 116, a low k-value dielectric material 118, and contact pads 120 that are the same as the sintered ceramic base structure 12, capacitor structure 16, and contact pads 20 of the interposer substrate 10 of **Figure 1**. The package substrate 138 differs from the interposer substrate 10 in that conductive lines 150 are provided instead of the conductive vias 14.

[0027] Each one of the conductive lines includes two vertical vias 156 and 158 and a horizontal line 160 interconnecting the vertical vias 156 and 158. The sintered ceramic base structure 112 is formed in stages so that the horizontal line 160 is buried below an upper surface of the sintered ceramic base structure 112. The horizontal line 160 allows for the vertical vias 156 and 158 to be horizontally offset with respect to one another. The horizontal lines 160 thus allow for x-y transformation on the vertical vias 156 to the vertical vias 158.

[0028] **Figure 4** illustrates an integrated circuit package 134 which includes the package substrate 138, a carrier substrate 136, and a die 140. The die 140 and carrier substrate 136 are the same as the die 40 and carrier substrate 36 of the integrated circuit package 34 of **Figure 2**. The integrated circuit package 134 differs from the integrated circuit package 34 in that there is no intermediate interposer substrate between the die 140 and the package

substrate 138. In the integrated circuit package 34 of **Figure 2**, the interposer substrate 10 provides a capacitor structure 16 close to the die 40 and the package substrate 38 provides an x-y transformation. In the integrated circuit package 134 of **Figure 4**, by contrast, the package substrate 138 provides a capacitor structure 116 close to the die 140 and provides x-y transformation.

[0029] **Figure 5** illustrates an interposer substrate 210 according to a further embodiment of the invention. The interposer substrate 210 has a sintered ceramic base structure 212, conductive vias 214, upper and lower capacitor structures 216A and 216B, a low k-value dielectric material 218, and upper and lower contact pads 20A and 20B.

[0030] The base structure 212 is initially made of a green, i.e., unsintered material. The green material is packaged in the shape of the base structure 212, and via openings 222 are then punched through the green material. The green material is subsequently sintered so that the green material becomes a sintered ceramic material, and the base structure 212 becomes a sintered ceramic base structure 212. The sintered ceramic base structure 212 then has the via openings 222. The via openings 222 include a power via opening 222P, a ground via opening 222G, and signal via openings 222S. Each one of the via openings 222 extends from a lower surface through an upper surface of the horizontal sintered ceramic base structure 212.

[0031] The low k-value dielectric material 218 is then formed on the upper and lower surfaces of the sintered ceramic base structure 212. The low k-value dielectric material 218 is then patterned. The capacitor structures 216A and 216B are subsequently formed on exposed areas of the upper and lower surfaces of the sintered ceramic base structure 212, the vias 214 are formed, and the contact pads 20A and 20B are formed on upper and lower surfaces of the resulting structure. The manufacture of the interposer substrate 210 of

Figure 5 is thus exactly the same as the manufacture of the interposer substrate 10 of **Figure 1**, except that the portions on top of the sintered ceramic base structure 12 in **Figure 1** are manufactured on upper and lower surfaces of the sintered ceramic base structure 212 of **Figure 5**.

[0032] What should be noted is that the power conductive via 214P is connected to both capacitor structures 216A and 216B. Similarly, the ground conductive via 214G is connected to opposing terminals of both capacitor structures 216A and 216B. The dual capacitor structures 216A and 216B provide twice as much capacitance as the single capacitor structure 16 of **Figure 1**. Each capacitor structure 216A or 216B includes a small number of layers. By maintaining the number of layers small, it is easier to maintain more uniform surfaces during the manufacture of a capacitor structure 216A or 216B.

[0033] Each one of the signal conductive vias 214S is disconnected from both the capacitor structures 216A and 216B. As for the interposer substrate 10 of **Figure 1**, the interposer substrate 210 of **Figure 5** allows for power, ground, and signals to be routed therethrough.

[0034] **Figure 6** illustrates the interposer substrate 210 within an integrated circuit package 234. The integrated circuit package 234 is identical to the integrated circuit package 34 of **Figure 2**, except that the interposer substrate 10 of **Figure 2** is replaced with the interposer substrate 210 of **Figure 5**, with the additional benefit that increase capacitance is provided.

[0035] While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative and not restrictive of the current invention, and that this invention is not restricted to the specific constructions and arrangements shown and described since modifications may occur to those ordinarily skilled in the art.